CHAPTER 8

Channel Width

8-1. Design Criteria.

a. *Design Factors.* The design width of the channel will be determined to accommodate the design ship(s) representative of the project forecasted user fleet. This width need not be constant throughout the project but may vary as necessary so that the design ship can make a safe, efficient, and cost-effective transit of the channel under the set of operational conditions chosen. The channel width required will depend on the following main factors:

(1) Design ship beam, length, and draft.

(2) Local piloted ship control.

(3) Channel cross section and alignment.

(4) River and tidal currents.

(5) Navigation traffic pattern (one- or two-way).

(6) Vessel traffic intensity and congestion.

(7) Wind and wave effects.

(8) Visibility.

(9) Quality and spacing of navigation aids.

(10) Composition of channel bed and banks.

(11) Variability of channel and currents.

(12) Speed of design ship.

b. *Other Considerations.* The design channel width is defined as the width measured at the bottom of the side slopes on each side of the channel at the design depth. Upon project authorization, the design widths are considered, nominally, to be the authorized widths. This should not preclude minor adjustments in width during continued design, construction, and operation as circumstances warrant and delegated authorities permit. The specified width provides for local increases at entrances, bends, turns, sidings, and maneuvering and turning basins as required to allow normal ship operations in a safe and efficient manner. Physical models and ship simulator techniques can be used to assess the safety and efficiency of alternative channel design widths. Paragraph 8-2 discusses preliminary channel design, especially at the initial stage of navigation projects.

8-2. Channel Alignment.

a. *Design.*

(1) To minimize initial and maintenance dredging, the alignment of a navigation channel is usually designed to follow the course of the deeper channel in a river or estuary. The channel layout should also consider the effects of speed and direction of currents as well as predominant wind conditions on ship navigation. In general, currents aligned with the channel are desirable to reduce the adverse navigation effects from crosscurrents. In tidal flow situations, there are often separate flood and ebb natural channels, which may not be the same. In meandering river waterways, navigation channel crossings from one outside bend channel to the next will also require dredging through natural shoal areas. Circular bends in alignment should not be necessary, except in large angular deflection channel turns. An alignment consisting of straight reaches with small turns between channel segments permits pairs of range markers to be located on the channel centerline. This provides for better channel location and ship pilot control than other possible channel aids to navigation. The straight segments between turns should be at least five times the length of the design ship. Most channel turns should be designed with cutoffs on the inside of the turn as described later in this chapter. Training structures, such as dikes, jetties, breakwaters, revetments, and wave absorbers, might be required to maintain acceptable channel alignment and dimensions and reduce wave conditions. The location and placement of these structures will have an impact on the channel navigability in addition to sediment movement and require careful design. Channel alignment that cuts across sandbars and mud banks should be avoided, if possible; training structures to control the movement and deposition of sediment will usually be required. As a general rule, entrance channels should be aligned parallel to the propagating direction of predominant waves. With this alignment, wave-generated crosscurrents and ship wave response are avoided and result in advantageous effects on both sedimentation control and ship handling.

(2) Channel alignment option studies should consist of selecting several alternate routes and developing construction and maintenance costs for each. Project benefits for each alignment will involve improvements associated with relative ship transit times. A comparison of annual project costs and benefits will determine the optimum channel alignment.

8-3. Channel Cross Section.

a. *Channel Variability.* The cross section of navigation channels varies substantially, depending on local project conditions, as well as along the length of the channel in the same waterway. Figure 8-1 presents example cross sections for three of the main types. It is possible to classify the channel geometry into four types of cross sections to develop channel-width criteria in a rational way, taking into account parameters that govern ship navigation. The usual “at sea” unconfined ship operating water environment is modified considerably in the normal restricted channel or waterway cross sections, which are defined and explained below:

(1) *Shallow water*. Wide, unrestricted waterways without channel banks, near the ocean end of entrance channels, usually provided with range markers and channel edge buoys. Substantial bottom effects but negligible bank forces and thus no noticeable vessel reaction to the proximity of the channel edge. Strong ship yawing forces from crosscurrent effects and wave action.

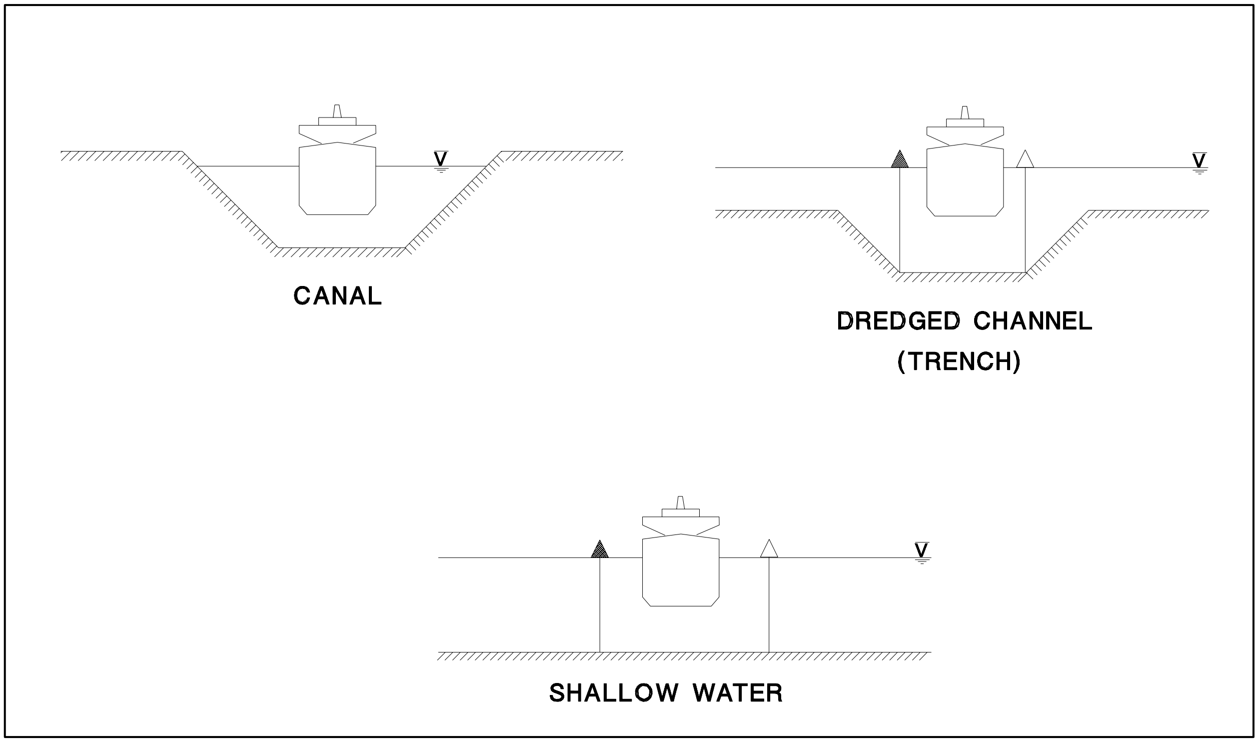

Figure 8-1. Channel cross sections

(2) *Canal*. Narrow, fully restricted channels with clear and visible banks often with only minimal aids to navigation. Negligible yawing forces occur, since currents are aligned with the channel, except at turns. Strong bank effects with off-center-line ship position and good bank cues.

(3) *Trench*. Dredged- or open-type restricted channels, intermediate between canals and shallow water, with submerged banks on each side, usually provided with range markers and channel edge buoys or beacons. Some ship yawing forces from crosscurrent and wave effects on ship navigation are often present with variable bank effects. Bank cues can be important in piloting. Magnitude of yawing forces dependent on overbank depth on each side of the sailing ship and crosscurrents, waves, and winds.

(4) *Asymmetric*. Different depths or bank conditions on each side of a channel centerline (stepped channels) or other combinations of asymmetry about the center or sailing line. In addition to range markers and beacons, channel edge steps are sometimes marked by special buoys. Possible strong bank force effects can be experienced with some ship yawing. There is a tendency for a ship to drift away from channel centerline.

8-4. Interior Channels.

a. *Design Methodology*. Harbor access channels leading from the bar or entrance channel to the port area are referred to as interior channels. For straight channels without any turns, the required channel widths to accommodate a given design ship should be determined based on the following factors in the order of importance:

(1) Traffic pattern (one-way or two-way).

(2) Design ship beam and length.

(3) Channel cross section shape.

(4) Current speed and direction.

(5) Quality and accuracy of aids to navigation.

(6) Variability of channel and currents.

Design widths have, in the past, been based on dividing the total required width into a maneuvering lane and a bank clearance lane. The criterion was developed by assigning three levels of ship controllability and judgment as the main factors to consider in channel width design. Methods to deal with these factors have not been developed. Evaluation of many navigation project studies on the ERDC/WES Ship Simulator has shown that professional pilots do not think in a manner or control ships in a way that makes such channel width division logical. In fact, pilots routinely use the bank effects as a cue in determining ship position by deliberately moving the ship off the channel centerline toward the bank. Since there is no particular advantage in assigning a value to a maneuvering and a bank clearance lane, an alternative method has been developed. The following procedure refers to total channel width and incorporates the six factors listed above as the most important in deciding the design channel width. Figure 8-2 presents two examples of channel width definition.

b. Width Criteria. Numerous studies have been made reviewing generally accepted design practice in dimensioning channel widths for ship navigation. For one-way ship traffic, values vary from 2.0 to 6.0 or even 7.0 times the design ship beam. A range of 2.8 to 5.0 had been developed based on McAleer, Wicker, and Johnston (1965) and used for design criteria. Simulator studies have consistently showed that it is possible to control ships sailing in quite narrow channels and that the available Corps and international design criteria are overly conservative. In particular, simulator tests on the Sacramento River and the Brazos Island Harbor both indicate that uniform, straight canals with very small currents resulted in recommended channel widths near 2.0 times the design ship beam. Table 8-1 summarizes these test results.

Table 8-1
Channel Design Width Tests

Simulation Study	Design Ship Beam, m (ft)	Recommended Channel Width, m (ft)	Width/Beam, m (ft)
Brazos Island Harbor	32 (106)	76 (250)	0.7 (2.4)
Sacramento River	28 (93)	61 (200)	0.3 (2.2)

Based on these test results, a value of 2.5 times the design ship beam for canals with negligible currents should be conservative. Using this value and other available data, Table 8-2 is proposed for interim use in one-way channels:

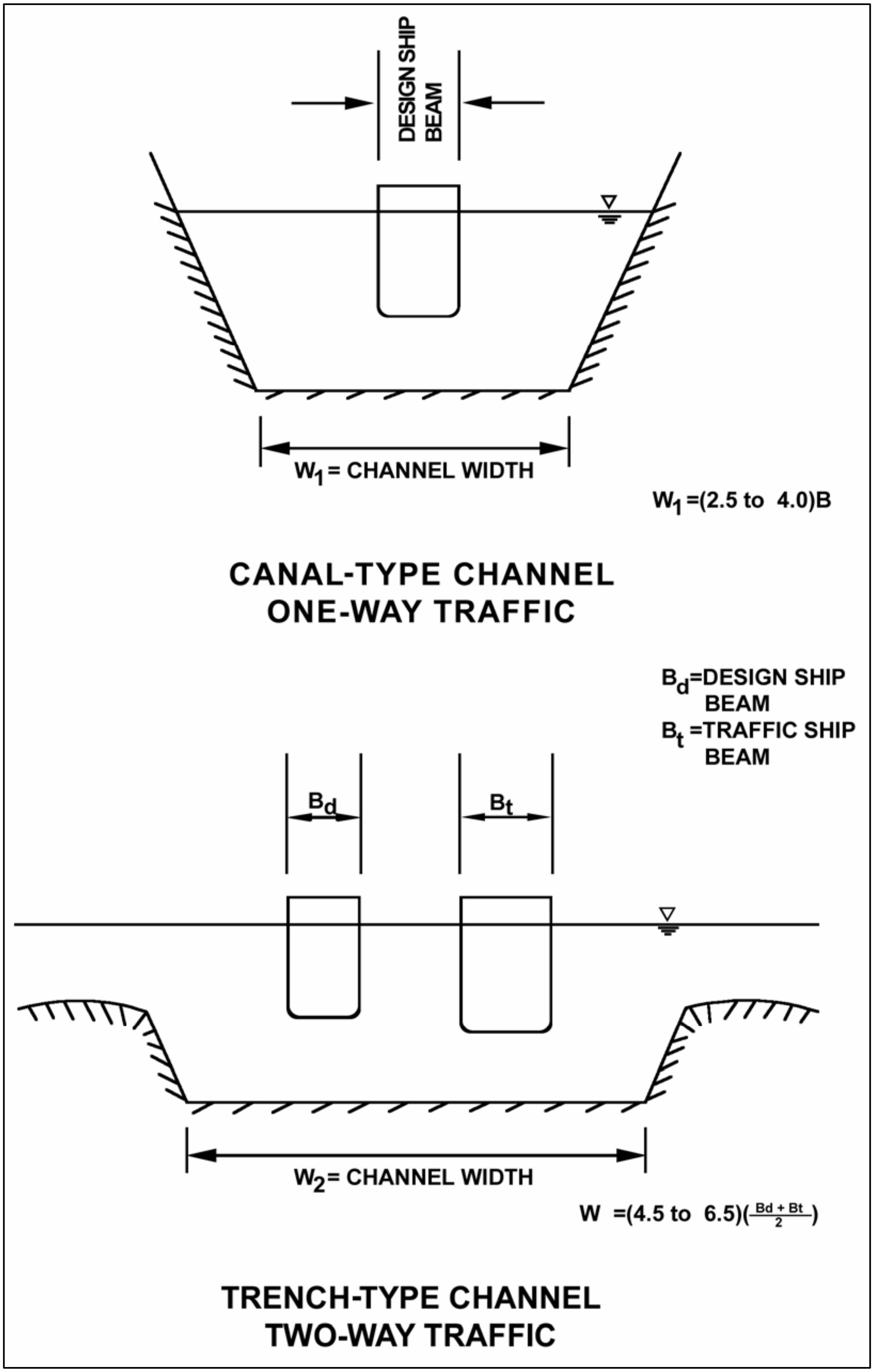

Figure 8-2. Channel design width

Table 8-2
One-Way Ship Traffic Channel Width Design Criteria

Channel Cross Section	Design Ship Beam Multipliers for Maximum Current, Knots		
	0.0 to 0.5	0.5 to 1.5	1.5 to 3.0
Constant Cross Section, Best Aids to Navigation			
Shallow	3.0	4.0	5.0
Canal	2.5	3.0	3.5
Trench	2.75	3.25	4.0
Variable Cross Section, Average Aids to Navigation			
Shallow	3.5	4.5	5.5
Canal	3.0	3.5	4.0
Trench	3.5	4.0	5.0

Developing a similar table for two-way ship traffic is difficult because of lack of simulator data. An analysis of published criteria shows a similar highly conservative basis for design. Recent testing on the Houston Ship Channel resulted in data that were also used to develop Table 8-3.

Table 8-3
Two-Way Ship Traffic Channel Width Design Criteria

Uniform Channel Cross Section	Design Ship Beam Multipliers for Maximum Current, Knots (ft/sec)		
	0.0 to 0.5 (0.0 to 0.8)	0.5 to 1.5 (0.8 to 2.5)	1.5 to 3.0 (2.5 to 5.0)
Best Aids to Navigation			
Shallow	5.0	6.0	8.0
Canal	4.0	4.5	5.5
Trench	4.5	5.5	6.5

The design channel width for navigation projects with maximum currents greater than 3.0 knots should be developed with the assistance of a ship simulator design study. Furthermore, bank suction can significantly affect ship maneuvering in narrow channels; however, there is no simple analytical relationship between these effects and channel width design criteria. Bank effects should be considered during channel design and can be handled most efficiently through the use of numerical modeling techniques such as those used in a ship simulator.

8-5. Entrance Channels.

a. Entrance Channel Navigation.

(1) Navigation in entrance channels is often affected adversely by strong and variable (in space and time) tidal currents, rough seas and swell, breaking waves, and wind. In some places, frequent fog, snow, and rain will also cause visibility problems. At some level of ship control difficulty, the navigation traffic may be stopped through the port entrance channel or bar by the U.S. Coast Guard, local pilots, or other entity, i.e., the bar is "closed." It is important that the project planner/designer develop operational information on bar closure conditions to be able to design an optimum entrance channel width without compromising safety. Depending on local conditions, safe navigation will usually require a wider and deeper entrance channel than the port interior channels. The magnitude of this is difficult to estimate but should be based primarily on horizontal ship motion from wave effects. It may be necessary in some cases to design the entrance channel for two-way traffic because of the intensity of port navigation, which would increase channel width even more.

(2) Bar channels and entrances protected by jetties and training structures will require special studies of tidal currents, wave conditions, littoral drift, and shoaling tendencies to determine the optimum channel width and structure arrangement. Other design parameters such as channel alignment, required cross section, and degree of harbor wave action can also be developed during such a study. Each project will require substantial information on local conditions for the design analysis and evaluation studies needed for judicious overall project design.

b. *Entrance Channel Width.* The width allowance in excess of the interior channel width to account for wave effects on horizontal ship motion is difficult to estimate. A recent project for Barbers Point Harbor using a physical model study at the Coastal and Hydraulics Laboratory (CHL) at ERDC/WES (Briggs et al. 1994) included extensive measurements of ship model motion and piloting to help design the entrance channel. Another project on the San Juan Harbor involved a mathematical model of ship response and piloting on the WES ship simulator (Webb 1993) to develop a safe and adequate entrance channel. These two references should be reviewed and the individuals at ERDC/WES consulted to gain the most recent information. Field data measurements of ship horizontal motion were also conducted at the Mouth of the Columbia River project and should also be reviewed (Wang et al. 1980).

8-6. Channel Turns and Bends.

a. *Ship Turning Maneuver.* The swept path of a ship making a turn is wider than its swept path in a straight channel simply because of the geometry of the turning ship. Experience has shown that controllability of a ship while turning is degraded compared to maneuvering in a straight channel, thus causing a wider swept path. The width of the swept path is dependent on the following:

(1) Ship yaw angle while turning.

(2) Length and beam of the ship.

(3) Ship rudder angle.

(4) Possible use or nonuse of kick turning by the pilot.

(5) Location and spacing of aids to navigation in the turn.

(6) Local current and other environmental conditions.

If the turning is in a given channel configuration, the channel turn radius, the deflection angle of turn, and the channel width and variability will also have an impact. Generally, channels with turns and bends are more difficult to navigate compared with straight reaches because of reduction in sight distance, reduced effectiveness of aids to navigation, changing channel cross-sectional area, and greater effect from varying current and bank suction forces.

b. *Channel Width in Turns.* Since the swept path of a ship making a turn is wider than the path in a straight channel reach, a greater channel width is required in turns and bends. The swept path of a turning ship is dependent mainly on the channel turn radius and the ship length. Figure 8-3 presents a definition sketch of the relevant variables and a plot giving required channel width increase in turns. The deflection angle of the channel turn may also be a factor resulting from the piloting and ship control difficulty while maneuvering a ship around a channel turn. Since pilots often use the bank effects to assist in a turn, the bank conditions are also very important to the design of the turn. However, the recommended turn design does not include bank effects. The graph shown in Figure 8-3 can be used to relate the required channel width increase in a turn for design purposes. Channel turns should not be designed for turn radius-to-ship length ratios less than 3, because ships cannot hydrodynamically maneuver around a sharper turn. Table 8-4 summarizes the recommendations on channel turn configurations including channel width increases in the turn. The table includes recommended turn radius-to-ship length ratios as a function of the turn deflection angles. Figure 8-4 gives a definition and geometric relations for each recommended turn type.

c. *Turn Design.* The channel turn width increase indicated in Table 8-4 can be designed in several ways. Recommendations for specific turn types varying from a straightforward (unwidened) angle to connecting circular arcs are also presented in the table as a function of the turn deflection angle (Figure 8-4). In general, the greater the deflection angle, the longer the channel turn or curve for a given turn radius. A common method to provide the additional channel width is the apex or cutoff method, which provides the turn width increase on the inside of the turn using a single straight line. Alternatively, multiple straight lines can be used to replace the single line on the inside of the turn. In some cases, the outer point can also be cut off, since ships would not use the outer turn apex. The apex turn may produce adverse current patterns, especially in canals or high current situations, which would be detrimental to ship navigation. An alternative turn may be designed using circular arcs with parallel or nonparallel banks. The width increase is provided through the turn with transitions to the straight channel segments on each end of the turn. Transitions assist pilots in maintaining control as the ship is steered out of the turn.

Table 8-4
Recommended Channel Turn Configurations

Deflection Angle, Deg	Ratio of Turn Radius/ Ship Length	Turn Width Increase Factor (* Ship Beam)	Turn Type
0 - 10	0	0	Angle
10 - 25	3 - 5	2.0 - 1.0	Cutoff
25 - 35	5 - 7	1.0 - 0.7	Apex
35 - 50	7 - 10	0.7 - 0.5	Curved
>50	>10	0.5	Circle

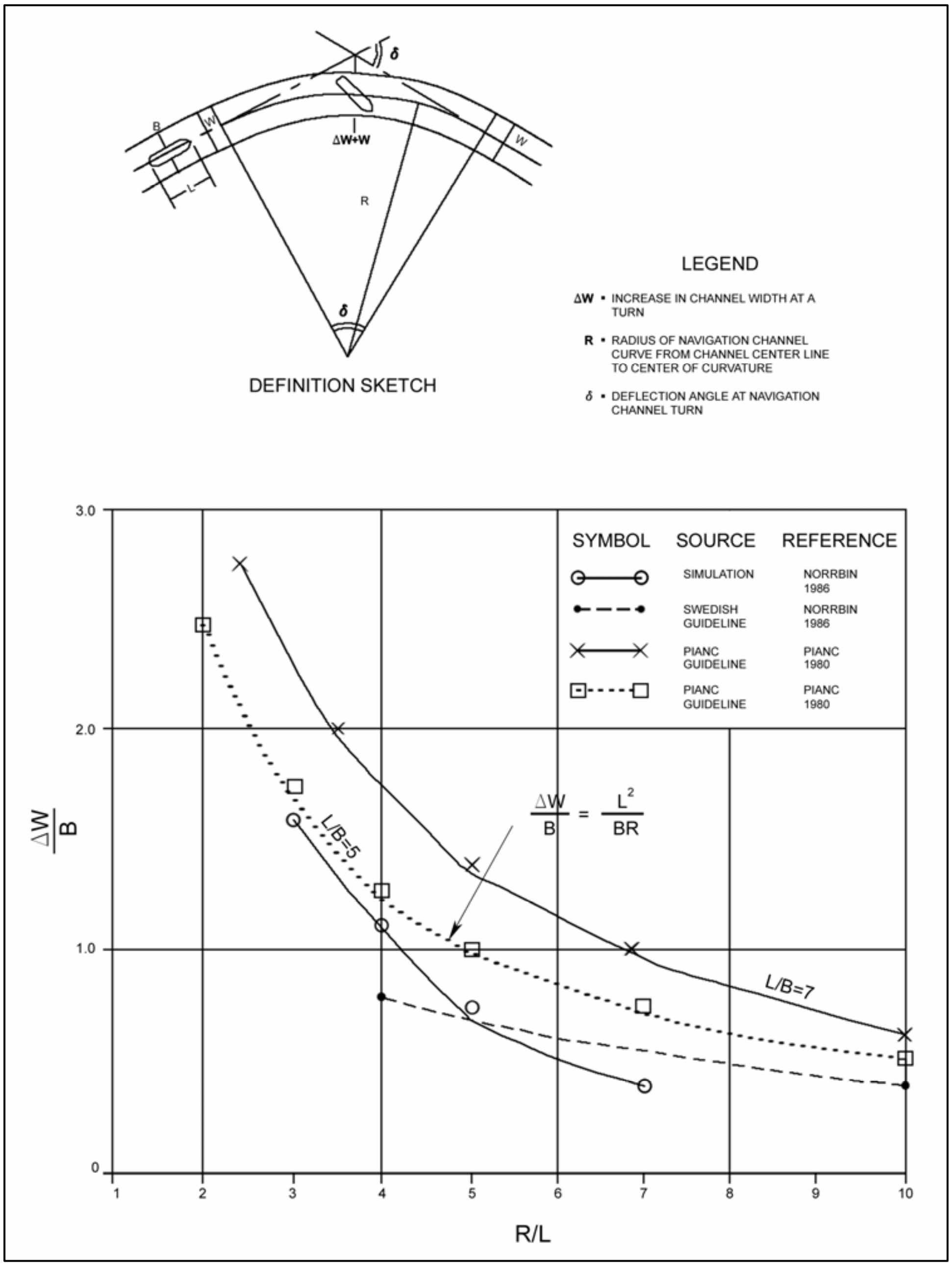

Figure 8-3. Channel width increase in turns

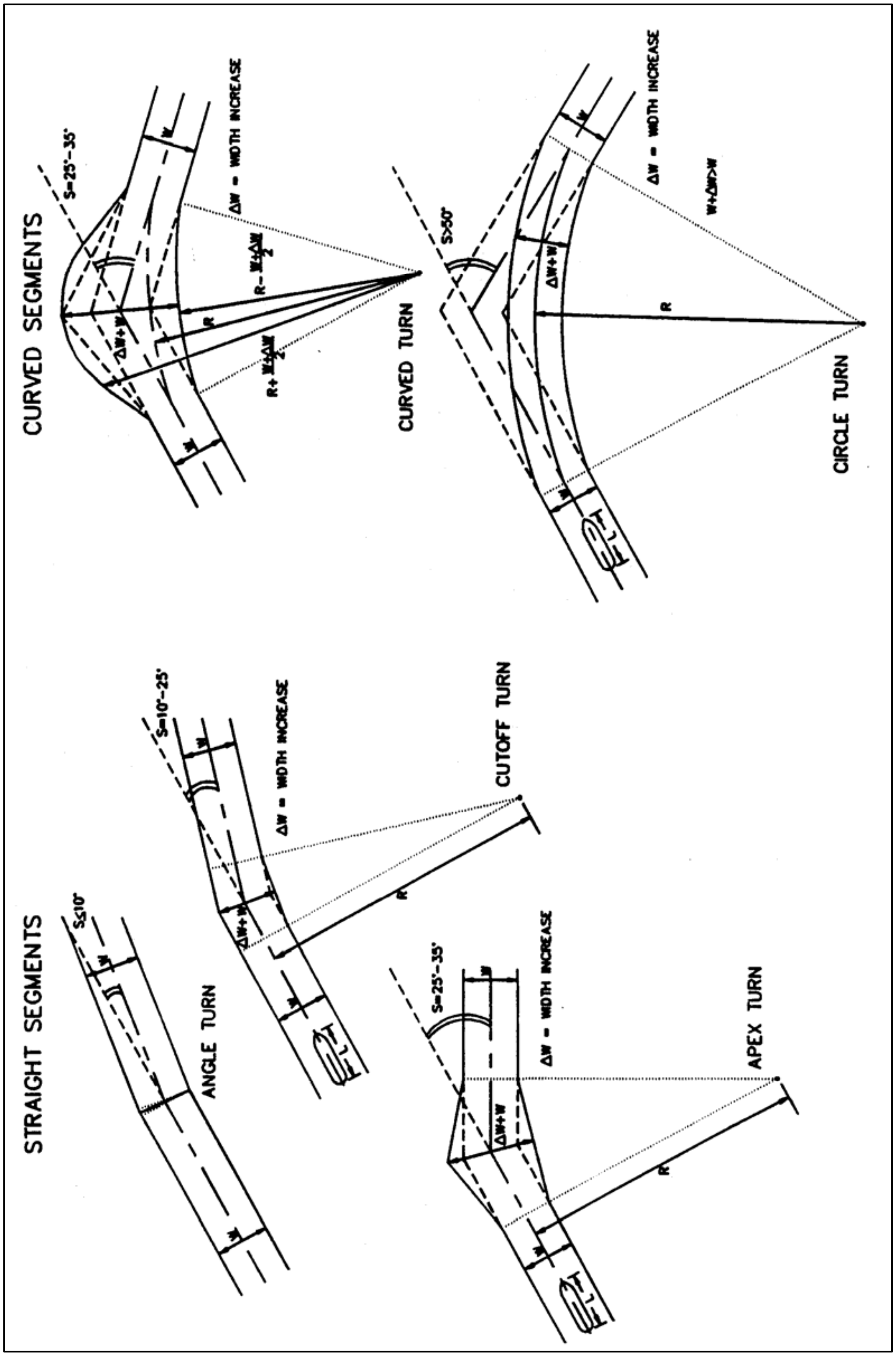

Figure 8-4. Channel turn configurations

d. *Width Increase.* Increasing the width of channels in turns could affect the current pattern alignment, which may tend to cause ship steering problems. Channel shoaling tendencies could also be affected and rates and location of shoaling areas changed. The local effects of currents, wind, waves, and visibility on ship piloting must be evaluated for each project. Physical ship models and appropriate testing facilities are available at ERDC/WES to conduct design studies when required. Numerical models of currents and sediment movement in conjunction with the ERDC/WES ship simulator can provide comprehensive study capabilities when warranted by the project.

e. *Successive Turns.* Successive turns or double bends can be reverse turns (S-bends) or consecutive (U-type) turns. An important variable is the length of straight segment between turns that should be provided to allow the ship pilot to regain control prior to starting the maneuvers for the second turn. Swedish research by Norrbin (1986) indicates that at least five times the design ship length of straight segment should be allowed between successive turns. In some cases, the physical constraints will dictate tighter turns, perhaps with little, if any, straight segments between turns. Design of such special circumstances should be done by using ship simulation testing to develop appropriate channel alignments and dimensions.